

12

# EUROPEAN PATENT APPLICATION

21 Application number: 85112914.8

51 Int. Cl.<sup>4</sup>: H 01 L 41/08  
 G 01 S 7/52

22 Date of filing: 11.10.85

30 Priority: 15.10.84 US 661082

43 Date of publication of application:  
 21.05.86 Bulletin 86/21

84 Designated Contracting States:  
 AT BE CH DE FR GB IT LI NL SE

71 Applicant: Edo Corporation/Western Division  
 2645 South 300 West  
 Salt Lake City Utah 84115(US)

72 Inventor: Lapetina, Robert A.  
 4196 Abinadi Road  
 Salt Lake City Utah 84117(US)

72 Inventor: Snow, Gordon L.  
 2748 East 5141 South  
 Salt Lake City Utah 84117(US)

72 Inventor: Baird, P. David  
 1376 Lincoln Street  
 Salt Lake City Utah 84105(US)

74 Representative: Patentanwälte Grünecker, Kinkeldey,  
 Stockmair & Partner  
 Maximilianstrasse 58  
 D-8000 München 22(DE)

54 Flexible piezoelectric transducer assembly.

57 A flexible piezoelectric transducer assembly for producing sonar signals for transmission underwater and for detecting reflected sonar signals. The assembly includes a generally flat, flexible casing formed with a plurality of compartments, each of which is for receiving a piezoelectric element. A plurality of piezoelectric elements are disposed in each of the compartments and are coupled by way of conductors to electronic circuitry which produces electrical signals for stressing the piezoelectric elements and which processes electrical signals produced by the piezoelectric element in response to reflected sonar signals. The piezoelectric elements are spaced apart in the casing to allow flexing and bending, while also maintaining high packing density. The piezoelectric elements are also selected to have low cross-coupling characteristics.

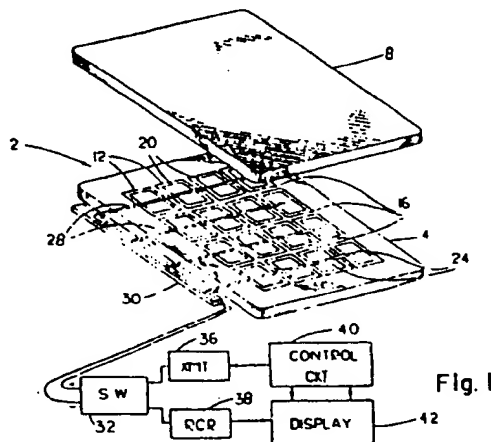


Fig. 1

EP 0 181 506 A2

Best Available Copy

1

5

10

## FLEXIBLE PIEZOELECTRIC TRANSDUCER ASSEMBLY

This invention relates to a piezoelectric transducer assembly having an array of piezoelectric elements embedded or held in a flexible casing.

15

Piezoelectric elements, primarily crystals and ceramics, are employed in a variety of devices including crystal microphones, ultrasonic devices, accelerometers and oscillators. One of the most common uses of piezoelectric elements is in underwater sonar equipment in which a piezoelectric sonar transducer is stimulated by electrical signals to emit sonar signals which radiate out from the transducer. The sonar signals are reflected from underwater objects and the reflected signals are detected by the transducer which produces electrical signals carrying information about the underwater objects.

25

1 Transducers typically used in underwater sonar  
equipment consist of either a single crystal or  
ceramic element or a rigid array of elements. It  
has been recognized that it would be desirable to  
5 have a flexible, conformable transducer which  
could be placed on various shaped surfaces for  
use. If a rigid transducer were applied to such  
surfaces and the surfaces were flexed or bent to  
any extent, the transducer could be damaged. A  
10 flexible, conformable transducer, however, would  
not only allow for ease of attachment to different  
shaped surfaces, but would also accommodate flexing  
and bending of the surface on which the transducer  
was placed.

15

There have been a number of proposals for providing  
flexible transducers including grinding up of  
piezoelectric material, embedding the material in  
an elastic material, and then attempting to polarize  
20 the entire unit so that it will function as a  
piezoelectric device. This type of unit, however,  
is typically very difficult to manufacture, sensitive  
to hydrostatic pressure changes and lacking in  
uniformity. Also, it is difficult to achieve  
25 consistency of characteristics from one unit to  
the next.

1 It is an object of the invention to provide a piezoelectric transducer assembly which is flexible and conformable to surfaces on which the assembly may be placed.

5

It is also an object of the invention to provide such an assembly which is easy to manufacture and whose quality can be readily controlled.

10 It is a further object of the invention to provide a piezoelectric transducer which is fairly immune to high pressures.

15 It is an additional object of the invention to provide a generally planar or linear, flexible piezoelectric transducer which can be shaped to focus or direct the sonar beams produced by the transducer as desired.

20 The above and other objects of the invention are realized in an illustrative embodiment of a flexible piezoelectric transducer assembly which includes an encasement made of a flexible, resilient material and having a generally flat profile, where the  
25 encasement includes a number of compartments spaced apart generally in a plane in the encasement. Also included are a plurality of piezoelectric

1 elements, each disposed in a different compartment  
of the encasement, and flexible conductors or  
conductive coatings which are arranged to extend  
through the encasement into contact with the  
5 elements for carrying externally generated electrical  
signals to the elements to stress the elements,  
and for carrying to a signal processor or other  
utilization device electrical signals produced by  
the piezoelectric elements when the elements are  
10 stressed.

With the above construction, the encasement holding  
the piezoelectric elements may be flexed or bent  
to conform to different mounting surface shapes.  
15 Advantageously, each piezoelectric element is  
polarized prior to installation in the encasement  
and so manufacture of the transducer assembly is  
simplified. A variety of materials might be used  
for the encasement including polyurethane, polyethelene,  
20 neoprene rubber, etc.

In the drawings:

The above and other objects, features and advantages  
25 of the invention will become apparent from a  
consideration of the following detailed description  
presented in connection with the accompanying  
drawings in which:

1       FIG. 1 shows a perspective, exploded view of  
a flexible planar piezoelectric transducer  
assembly made in accordance with the principles  
of the present invention;

5

FIG. 2 is a side, fragmented cross-sectional  
view of the piezoelectric transducer assembly  
of FIG. 1;

10

FIG. 3 is a top, plan, fragmented view of the  
base portion of a flexible piezoelectric  
transducer assembly showing triangular-shaped  
piezoelectric elements;

15

FIG. 4 is a side, fragmented cross-sectional  
view of a flexible piezoelectric transducer  
assembly which utilizes conductive sheets for  
carrying electrical signals to and from the  
piezoelectric elements;

20

FIG. 5 is a side, partially cutaway view of a  
line-array piezoelectric transducer assembly  
made in accordance with the principles of the  
present invention;

25

FIG. 6 is a perspective view of an alternative  
embodiment of a piezoelectric element which  
could be used in the assembly of FIG. 5; and

1           FIG. 7 is a perspective view of still another  
embodiment of a piezoelectric element which  
could be used in the FIG. 5 assembly.

5       Referring now to the drawings:

Referring to FIG. 1, there is shown an illustrative  
embodiment of a flexible planar piezoelectric  
transducer assembly which includes a two-piece  
10   housing or casing 2 having a base section 4 and a  
cover section 8. Both sections are made of a  
flexible, resilient material such as polyurethane,  
polyethelene, neoprene rubber, etc. When the  
cover section 8 is placed over and secured to the  
15   base section 4, the casing will present a generally  
flat profile as best seen in FIG. 2. The cover  
section 8 may be secured to the base section 4 by  
a suitable bonding agent such as polyurethane.  
The casing is formed to be generally square, but  
20   could take other shapes such as rectangular,  
circular, triangular, etc.

Formed in the base section 4 of the casing are a  
plurality of generally rectangular compartments  
25   12. These compartments are formed to be fairly  
closely packed and nested in the manner shown in  
FIG. 1 to provide precise spacing of piezoelectric

- 1 elements (to be discussed momentarily). Adjacent  
compartments are separated by walls 16 integrally  
formed in the base section 4. Alternatively, a  
single large hollow or compartment may be formed  
5 in the base section 4 and then the piezoelectric  
elements (to be discussed momentarily) positioned  
in the hollow, separated from one another and held  
in place by an adhesive.
- 10 A plurality of piezoelectric elements 20, either  
crystal or ceramic, are also provided, with each  
piezoelectric element being placed in a different  
one of the compartments and held in place by an  
adhesive. The piezoelectric elements 20 are  
15 formed to fit snugly in each compartment and thus,  
for the embodiment of FIG. 1, the elements are  
shown as having a generally rectangular shape to  
conform to the shape of the compartments. The  
elements 20 have a thickness which is greater than  
20 the depth of the compartments, such thickness  
being less than the length and width of the elements.

Thin conductive films 24 are placed on the upper  
and lower surfaces of each of the piezoelectric  
25 elements 20 (advantageously during manufacture of  
the elements) to enable poling of the elements  
during manufacture and to serve as electrodes for



- 1     applying electrical signals to the elements. Such  
films could be any suitable conductive material  
such as silver, a silver alloy, etc.
- 5     The piezoelectric elements 20 are selected to  
possess low cross-coupling to thereby reduce  
response in unwanted modes of operation and enable  
use of the elements over a wide band of frequencies  
without significant sensitive degradation. Suitable  
10    piezoelectric material for achieving this characteristic  
include lead mataniobate and lead titanate, among  
others.

- Conductive strips of material 28 are placed in  
15    contact with each of the conductive films 24 on  
the upper surfaces of the piezoelectric elements  
20, with conductive strips 28 extending through  
the casing to a bus 30 which is coupled to a  
transmit/receive switch 32. Conductive strips of  
20    material 34 (see FIG. 2) are placed in contact  
with conductive films positioned on the bottom  
surfaces of each of the piezoelectric elements 20  
to extend through the casing also to the bus 30.  
The conductive strips 28 and 34 could advantageously  
25    be strips of silver, copper, etc., held in contact  
with the conductive films by spot welding, soldering  
or conductive adhesive. Alternatively, the conductive

1 strips could be strips of flexible elastomer  
containing conductive (e.g. silver) particles of  
flakes. This latter arrangement would provide  
desired flexibility.

5

An alternative to the two-piece housing or casing  
2 of FIG. 1 would be a one-piece housing made, for  
example, by first supporting the piezoelectric  
elements, connecting wires, etc., in the desired  
10 configuration (using suitable tooling fixtures),  
and then encapsulating the entire array in the  
encasement material.

The circuitry for producing electrical signals to  
15 stress the piezoelectric elements 20, and for  
detecting the occurrence of stress in the elements  
includes, in addition to the transmit/receive  
switch 32, a transmitter 36 and receiver and  
signal processor 38 both connected to the switch  
20 32, a control circuit 40 connected to the transmitter  
36, and a display unit 42 connected to the control  
circuit 40 and receiver and signal processor 38.  
The control circuit 40, which might illustratively  
be a microprocessor, signals the transmitter 36 to  
25 apply electrical signals via the transmit/receive  
switch 32 to the piezoelectric elements 20 to  
stress the elements. The piezoelectric elements

1 20 are thus caused to produce, for example, sonar  
signals for underwater transmission. Reflected  
sonar signals intercepted by the piezoelectric  
elements 20 stress the elements and cause them to  
5 produce electrical signals which are applied via  
the switch 32 to the receiver and signal processor  
38. The receiver and signal processor 38 process  
these signals and then signals the display unit to  
display information representing the location and  
10 shape, for example, of underwater objects from  
which the sonar signals are reflected. The  
circuitry described is conventional, shown only  
for illustrative purposes, and does not form any  
part of the invention.

15

The overall size of the transducer assembly could  
be whatever is desired by the user, but would  
depend in part on the number of piezoelectric  
elements to be utilized. Advantageously, the  
20 piezoelectric elements 20 would have widths and  
lengths of between about 1/8 of an inch and several  
inches, and would have thicknesses of between  
about 1/100 of an inch and 1 inch. These dimensions  
facilitate ease of manufacture and piezoelectric  
25 poling. Of course, the smaller the piezoelectric  
element, the greater would be the flexibility and  
conformability of the transducer assembly. Employment

1 of a flexible casing 2 for holding the piezoelectric  
elements serves not only to accommodate the feature  
of flexibility and conformability, but also serves  
to isolate and protect the piezoelectric elements  
5 20 from shock, hydrostatic pressures, water and  
other fluids in which it would be used, and other  
external effects. With the generally flat profile  
of the transducer assembly, the assembly can be  
readily attached to flat mounting surfaces and to  
10 surfaces having shapes which are other than planar  
and which may change over time.

FIG. 2 shows a side, fragmented cross-sectional view  
of the transducer assembly of FIG. 1 including the  
15 base section 4 and cover section 8 of the casing,  
the piezoelectric elements 20, and a conductive  
strip 28 attached to the conductive films or  
electrodes 24 on the top surface of the piezoelectric  
elements, and a conductive strip 34 attached to  
20 the conductive films or electrodes on the bottom  
surface of the elements.

FIG. 3 shows a top plan view of a fragmented  
portion of a base section 44 of a casing, where  
25 the compartments 48 are formed in a triangular  
shape to accommodate triangularly-shaped piezoelectric  
elements. Of course, a variety of other shapes

1 could also be employed as earlier indicated. It  
is desirable, however, that the piezoelectric  
elements be closely packed and nested together and  
this is accommodated by either the rectangular or  
5 triangular shape.

FIG. 4 shows a side, fragmented cross-sectional  
view of a transducer assembly wherein sheets of  
conductive material 54 and 58 are respectively  
10 placed to contact all of the individual conductive  
films placed on the upper surfaces of the piezoelectric  
elements, and to contact all of the films or  
electrodes on the bottom surfaces of the elements.  
These conductive sheets would be provided for  
15 carrying externally produced signals simultaneously  
to all of the piezoelectric elements, and for  
carrying signals produced by all of the elements  
simultaneously to an external sink. This provision  
of conductive sheets of material is an alternative  
20 to the conductive strips 28 and 34 shown in FIG.  
1. Advantageously, the conductive sheets would be  
made of a composition of conductive particles and  
an elastomer, to provide flexibility for bending,  
etc.

25

FIG. 5 shows a partially cutaway view of a line  
array of piezoelectric elements 60 placed in a

1 flexible encapsulant 64 such as neoprene, polyurethane,  
or fluid such as oil or isopar, all of which are  
contained in a flexible hose or sleeve 68 made,  
for example, of neoprene, polyurethane or vinyle.

5 The sleeve 68 and encapsulant 64 surround the  
piezoelectric elements 60 to prevent water or  
other fluid in which the line array is used from  
reaching the elements. The piezoelectric elements  
60 shown in the drawing are elongate bars having a  
10 generally square cross-section, but they could be  
formed as solid cylinders, hollow cylinders,  
cubes of other shapes suitable for placement in a  
line array. The top sides of the piezoelectric  
elements 60 are coupled together by an electrical  
15 conductor 72 while the bottom sides are similarly  
coupled together by a conductor 76. These conductors  
both carry electrical signals to the piezoelectric  
elements 60 to stress the elements and cause them  
to produce sonar signals, and carry away electrical  
20 signals produced by the elements when the elements  
are stressed by reflected sonar signals. The  
conductors 72 and 76 would be coupled to circuitry  
similar to that shown in FIG. 1. If radially  
polarized solid cylinders were used as the piezoelectric  
25 elements, the conductors would be coupled to  
respective electrodes 80 and 84 disposed on opposite  
sides of the cylinders as shown in FIG. 6. If

1 radially polarized hollow cylinders were used, the  
conductors would be coupled to the inside and  
outside surfaces of the cylinders as shown in FIG.  
7.

5

It is to be understood that the above-described  
arrangements are only illustrative of the application  
of the principles of the present invention.

Numerous modifications and alternative arrangements  
10 may be devised by those skilled in the art without  
departing from the spirit and scope of the present  
invention and the appended claims are intended to  
cover such modifications and arrangements.

15

20

25

1

5

10

# CLAIMS

1. A flexible piezoelectric transducer assembly comprising

an encasement made of a flexible, resilient  
15 material and having a generally flattened profile,  
said encasement including a plurality of compartments  
spaced apart generally in a plane in the encasement,

a plurality of piezoelectric elements selected  
to have low cross coupling characteristics, each  
20 encapsulated in a different compartment of the  
encasement, and

conduction means coupled through the encasement  
to the elements for carrying electrical signals to  
the elements to stress the elements, and for  
25 carrying electrical signals produced by the elements  
when the elements are stressed.



1           2. A transducer assembly as in Claim 1  
wherein said encasement is formed of a generally  
planar base section an upper side of which is  
formed with said compartments, and a top section  
5 for placement on the upper side of the base  
section to enclose the compartments.

          3. A transducer assembly as in Claim 1  
wherein said encasement is made of polyurethane.

10

          4. A transducer assembly as in Claim 1  
wherein said encasement is made of polyethelene.

          5. A transducer assembly as in Claim 1  
15 wherein said encasement is made of rubber.

          6. A transducer assembly as in Claim 1  
wherein the compartments of the encasement holding  
the piezoelectric elements are formed in a closely  
20 packed and nested arrangement in the encasement.

          7. A transducer assembly as in Claim 6  
wherein the compartments and piezoelectric elements  
are generally polygonal in shape and dimensioned  
25 so that the elements fit snugly in the compartments.

1           8. A transducer assembly as in Claim 7  
wherein the compartments and piezoelectric elements  
are generally rectangular in shape.

5           9. A transducer assembly as in Claim 7  
wherein the compartments and piezoelectric elements  
are generally triangular in shape.

10           10. A transducer assembly as in Claim 1  
wherein the piezoelectric elements are generally  
flattened, and are selected to have low cross-  
coupling characteristics.

15           11. A transducer assembly as in Claim 10  
wherein the piezoelectric elements are made of  
lead titanate.

20           12. A transducer assembly as in Claim 10  
wherein the piezoelectric elements are made of lead  
metaniobate.

25           13. A transducer assembly as in Claim 1  
wherein the piezoelectric elements are formed  
generally in squares having a thickness of from  
about one-hundredth to one inch, and a width of  
from about one-eighth to about four inches.

1           14. A transducer assembly as in Claim 1  
wherein the piezoelectric elements are held in  
place in the compartments by an adhesive.

5           15. A transducer assembly as in Claim 1  
wherein the conduction means comprises  
            conductive sheets disposed on opposing sides  
of piezoelectric elements, and  
            conductive strips of material placed in  
10          contact with the conductive sheets and extending  
through the encasement to carry electrical signals  
from an external source to the sheets, and from  
the sheets to external electronics.

15          16. A transducer assembly as in Claim 15  
wherein said conductive strips are composed of a  
composition of conductive particles and elastomer.

            17. A transducer assembly as in Claim 1  
20          wherein the conduction means comprises  
            a first sheet of conductive material disposed  
in contact with one side of each of the piezoelectric  
elements,  
            a second sheet of conductive material disposed  
25          in contact with the other side of each of the  
elements, and

1           conductors for carrying electrical signals  
from an external source to the first and second  
sheets of material, and from the first and second  
5           sheets to external electronics.

18. A sonar transducer assembly comprising  
a casing made of a flexible, resilient material  
formed to have a thickness which is less than the  
length and width thereof, and including a multiplicity  
10 of compartments located in a side-by-side, nested  
relationship generally in a planar array,

a multiplicity of piezoelectric elements,  
each disposed in a different compartment and each  
having top and bottom surfaces which are generally  
15 parallel with each other and with the plane of the  
casing, each element being poled in the thickness  
direction and having low cross-coupling characteristics,

conductive sheets disposed on the top and  
bottom surfaces of the elements, and

20           conductors extending through the casing to  
contact the conductive sheets for carrying electrical  
signals to the sheets to stress the elements and  
cause them to emit sonar signals, and for carrying  
electrical signals produced by the elements when  
25           the elements intercept reflected sonar signals.

1        19. A flexible piezoelectric transducer  
assembly comprising

an array of spaced-apart piezoelectric elements  
arranged generally in a line and selected to have  
5 low cross-coupling characteristics,

conductor means coupled to the piezoelectric  
elements for carrying electrical signals thereto  
to stress the elements, and for carrying electrical  
signals produced by the elements when the elements  
10 are stressed,

means for supporting the piezoelectric elements  
in the array, and

means for preventing external access of fluid  
to the elements.

15

20. A transducer assembly as in Claim 19  
wherein said supporting means comprises a sleeve  
means in which are disposed the piezoelectric  
elements.

20

21. A transducer assembly as in Claim 20  
wherein the preventing means comprises a nonconductive  
encapsulant disposed about the piezoelectric  
elements to prevent access of fluid to the elements.

25

22. A transducer assembly as in Claim 19  
wherein said piezoelectric elements comprise

- 1 elongate bars having top and bottom surfaces, and  
wherein the conductor means comprise a pair of  
conductors, one of which is coupled to the top  
surfaces of each of the bars and the other of  
5 which is coupled to the bottom surfaces.

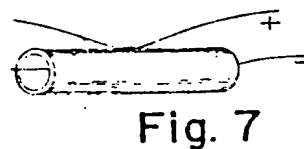
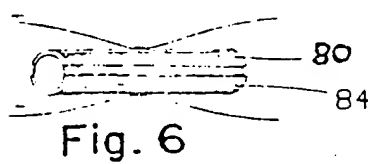
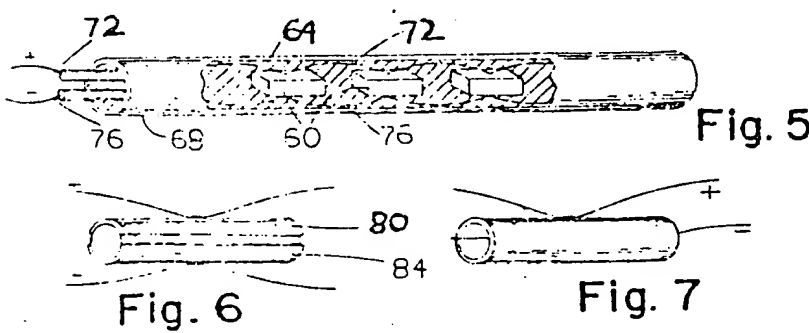
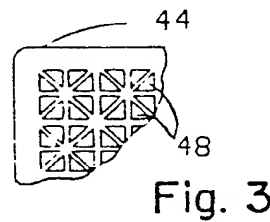
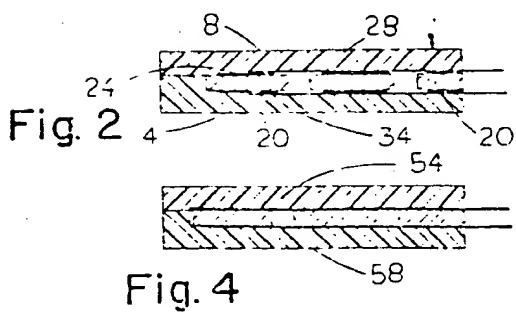
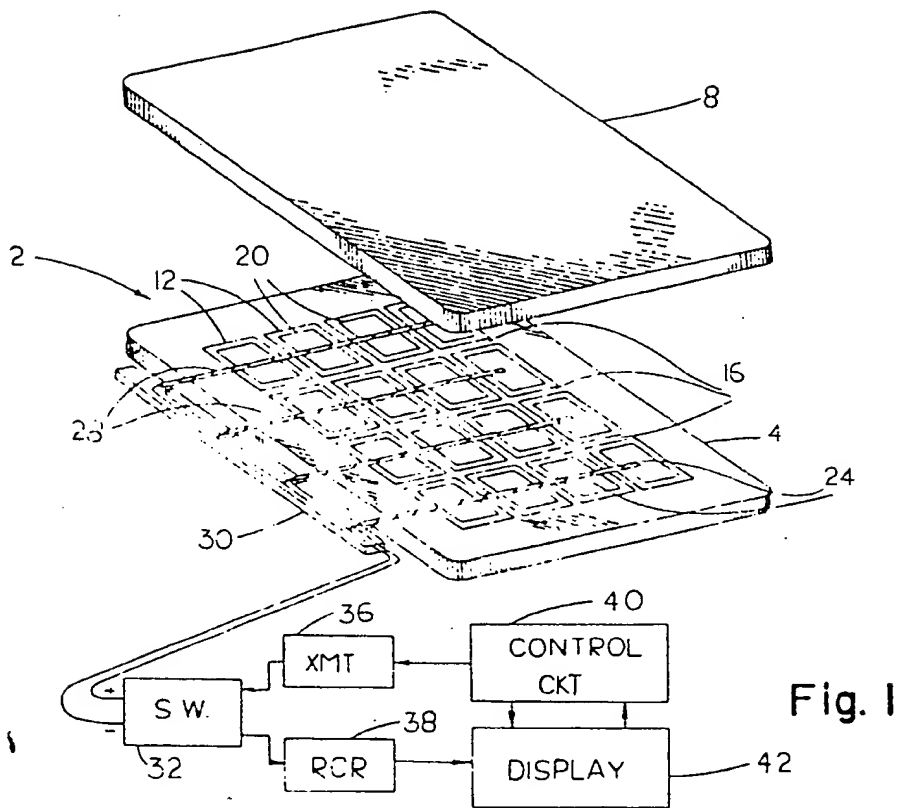
23. A transducer assembly as in Claim 19  
wherein said piezoelectric elements comprise  
elongate cylinders polarized in the radial direction,  
10 and wherein the conductor means comprise a pair of  
conductors, each of which is coupled to a respective  
opposing side surface of each of the cylinders.

24. A transducer assembly as in Claim 19  
15 wherein said piezoelectric elements comprise  
elongate, hollow cylinders polarized in the radial  
direction, and having inside and outside surfaces,  
and wherein the conductor means comprise a pair of  
conductors, one of which is coupled to the outside  
20 surfaces of each of the cylinders and the other of  
which is coupled to the inside surfaces.

25. A transducer assembly as in Claim 21  
wherein said encapsulant is a fluid.  
25

26. A transducer assembly as in Claim 21  
wherein said encapsulant is a flexible, resilient  
material.

1/1



**This Page Blank (uspto)**



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☒ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER: \_\_\_\_\_**

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**

**This Page Blank (uspto)**